Int J Life Cycle Assess (2012) 17:488–498
DOI 10.1007/s11367-012-0379-x

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

Statistical analysis for the development of national average weighting factors—visualization of the variability between each individual's environmental thoughts

Norihiro Itsubo · Masaji Sakagami · Koichi Kuriyama · Atsushi Inaba

Received: 30 March 2011 / Accepted: 6 January 2012 / Published online: 3 February 2012

Abstract
Purpose Weighting is one of the steps involved in life cycle impact assessment (LCIA). This enables us to integrate various environmental impacts and facilitates the interpretation of environmental information. Many different weighting methodologies have already been proposed, and the results of many case studies with a single index have been published. However, a number of problems still remain. Weighting factors should be based on the preferences of society as a whole so that the life cycle assessment (LCA) practitioner can successfully apply them to every product and service. However, most existing studies do not really measure national averages but only the average of the responses obtained from the people actually sampled. Measuring the degree of uncertainty in LCIA factors is, therefore, one of the most important issues in current LCIA research, and some advanced LCIA methods have tried to deal with the problem of uncertainty. However, few weighting methods take into account the variability between each individual's environmental thoughts. LIME2, the updated version of life cycle impact assessment method based on endpoint modeling (LIME), has been developed as part of the second LCA national project of Japan. One of the aims of LIME2 is to develop new weighting factors which fulfill the following requirements: (1) to accurately represent the environmental attitudes of the Japanese public, (2) to measure the variability between each individual's environmental thoughts and reflect them in the choice of suitable weighting factors.
Methods This study adopted the technique of conjoint analysis, which is currently the most advanced methodology available in the field of environmental economics. Using a random sampling process, 1,000 individual responses were collected. Every response was based on an interview survey designed to minimize bias. We used a random parameter logit model to estimate the preferences of society. Statistical values based on this model can be considered to reflect the variability between each individual's environmental thoughts. The calculated results can then be used to develop integration factors in LIME2, enabling us to express LCIA results as a single index, such as external cost.
Results and discussion The calculated values were significant statistically at the 1% level (all p values for the safeguard subject coefficients were less than 0.0001), with the exception of "social assets." Based on the calculated results, two types of weighting factor, an economic valuation and a

Responsible editor: Mark Huijbregts

Electronic supplementary material The online version of this article (doi:10.1007/s11367-012-0379-x) contains supplementary material, which is available to authorized users.

N. Itsubo (✉)
Department of Environmental and Information Studies,
Faculty of Environmental and Information Studies,
Tokyo City University,
3-3-1 Ushikubo-nishi, Tsuzuki Ward,
Yokohama 224-8551, Japan
e-mail: Itsubo-n@tcu.ac.jp

M. Sakagami
Department of Economics, Faculty of Economics,
Nihon Fukushi University,
Okuda, Mihama-cho, Chita-gun,
Aichi 470-3295, Japan

K. Kuriyama
Division of Natural Resource Economics,
Graduate School of Agriculture, Kyoto University,
Oiwake-cho, Kitashirakawa, Sakyo-ku,
Kyoto 606-8502, Japan

A. Inaba
Department of Environmental and Energy Chemistry,
Faculty of Engineering, Kougakuin University,
1-24-2, Nishi-Shinjuku, Shinjuku-ku,
Tokyo 163-8677, Japan

dimensionless index, were obtained. A relative comparison of importance among these four categories indicates that "biodiversity" receives the highest level of recognition, followed by "human health" and "primary production," while the weight of "social assets" rate lower than the other safeguard subjects, in comparison. Using the calculated results produced by the RPL model, the probability density of the variables for individual preferences could then be derived and displayed. The coefficients of variance for the estimated weighting factors were relatively small (in the range from 0.1 to 0.3).

Conclusions Accurate weighting factors representing the environmental attitudes of the Japanese public are needed in order to conduct general-purpose LCA for Japanese products. Random, unbiased sampling throughout Japan and an interview survey carried out on 1,000 respondents enabled us to address and solve the problems found with past weighting methodologies. We confirmed that the results of comparisons carried out among safeguard subjects were statistically significant, and showed that the contents of the questionnaires were well understood by the respondents. This study succeeded in visualizing the variability between each individual's environmental thoughts in order to improve the transparency of the weighting factors—expressing the difference in individual preferences within a certain range. This data can be used to develop integration factors with statistical values which can then be applied to uncertainty analysis in future LCA case studies.

Keywords Conjoint analysis · Damage assessment · Weighting · LCA National Project · Life cycle impact assessment · LIME (Lifecycle Impact assessment Method based on Endpoint modeling) · Random parameter logit model · Safeguard subjects

Abbreviations

CVM	Contingent valuation method
DALY	Disability-adjusted life year
EINES	Expected increase in number of extinct species
JY	Japanese yen
LCIA	Life cycle impact assessment
LIME	Life cycle impact assessment method based on endpoint modeling
NPP	Net primary production
WTP	Willingness to pay

1 Introduction

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value choices. In environmental systems analysis tools like life cycle assessment (LCA), results need to be presented in a comprehensible way to make alternatives easily comparable. One way of doing this is to aggregate results to a manageable set by using weighting methods (Ahlroth et al. 2011). Weighting is defined as one of the steps involved in life cycle impact assessment (LCIA) (ISO 14040 2006; ISO 14044 2006) and a variety of approaches have been developed to date.

During the 1990s, a number of methods were proposed to determine the weights used to compare different impact areas such as global warming and acidification (Goedkoop 1995; Hauschild and Wenzel 1997; Müller-Wenk 1994; Yasui 1998; Itsubo 2000). Methods to determine the weights to be given to endpoints (damage-oriented approach) such as human health and biodiversity have also attracted attention because they impose less burden on the respondents—requiring fewer endpoint elements (five or less) than environmental issues (which can require ten elements or more). Various systems such as Eco-indicator 99 (Goedkoop and Spriensma 1999), EPS (Steen 1999), ExternE (EC 1998, 2005), and LIME (Itsubo et al. 2004, 2010) have proposed weighting factors (the economic value or weighting value of one unit of the damage sustained by the safeguard subject) based on damage-oriented approach. These methods can be broadly classified into either the panel method or the economic evaluation method.

Using the panel method, experts and general consumers evaluate environmental impacts by means of questionnaires or group discussions. Eco-indicator 99 derives integration factors (the economic value or weighting value of 1 U of the inventory item) from the weighting given by LCA experts, based on a comparison of three predefined safeguard subjects (human health, ecosystem quality, and resources). One characteristic of this method is that it classifies the weights in terms of different ways of thinking about the environment (hierarchist, egalitarian, and individualist). However, sample size is not always enough to ensure representativeness of the survey results.

Using the economic evaluation approach, environmental impacts are expressed in terms of relative amounts of money. To date, there has been a lot of discussion on how best to allocate economic values to environmental impacts and the insights obtained in this field of environmental economics have also been used for LCIA. EPS and ExternE cite the amount people are willing to pay using values obtained by the contingent valuation method (CVM) for integration of LCIA. Since the results of this evaluation are expressed in terms of relative amounts of money, it is a very useful method for application purposes.

Recently, several methods of economic evaluation have also been published in the scientific literature increasing the credibility and the review process. Examples of more recent methods are methods based on monetary valuation of endpoints

(Itsubo et al. 2004; Weidema 2009), the Ecotax method based on a monetary valuation of midpoints (Finnveden et al. 2006), and panel methods for midpoints (Soares et al. 2006). Methodological aspects of weighting methods are also reviewed and discussed by Ahlroth et al. (2011) and Mettier and Hofstetter (2005).

The results are not only easy to understand but can also be used for cost–benefit analysis. While the best way to allocate economic values to environmental impacts such as a loss of health or a decline in biodiversity is still in the development stage and has not yet been fully established, internationally recognized environmental evaluation reports such as the Stern Review (Stern 2006) and the TEEB Report (EC 2008) have adopted this type of economic indicator.

Previous integration studies have raised the following issues:

1. Representativeness

   In order to develop versatile integration factors which can be used for a range of applications, regardless of the product or user, the weighting factors used should represent the population as a whole, not just a sample group. Most existing integration studies use a sample mean based on test panels or questionnaire surveys involving several tens of people, at most. The results obtained may only apply to the sample group and may not be applicable to any other group. In the case of LIME, which is a method developed to evaluate environmental impacts in Japan, it is desirable to obtain weighting factors which can accurately represent the environmental attitude of the Japanese public, as a whole.
2. Individual variability associated with weighting

   Within any group, each individual member of the group makes different value judgments. However, there is a certain variability and characteristic distribution to these differences. The integration method originally used by LIME1 (Itsubo et al. 2004) did not take this individual variability within the value judgment process into account and only estimated the representative values of the group as a whole. Therefore, if the individual variability in value judgment could be quantified, this should increase the transparency of the weighting factors used.

2 Purpose of the study

Itsubo et al. (2004) applied the technique of conjoint analysis, which has been the focus of much attention in the fields of market research and environmental economics (Green et al. 1991), for the purpose of integrating LCIA methods, and developed statistically significant integration factors. However, this technique may still not ensure sufficient representativeness when expressing the way in which the Japanese public thinks about the environment, as the following issues still remain to be resolved:

1. Since the original survey was conducted on only 400 people in the Kanto region, the results are not capable of adequately measuring the environmental values of the Japanese public, as a whole.
2. Since the original survey was conducted using the mall intercept method, the results may have been biased at the sampling stage.
3. While the individuals sampled placed different values on the environment, there is no information available on the variability of these results.

To address the abovementioned issues, this study explored how best to develop weighting factors which could achieve a higher degree of social consensus and satisfy the following requirements:

(a) Development of versatile and highly representative weighting factors which can be used by the Japanese public for a range of different applications

(b) Calculation of statistical values of weighting factors

(c) Development of versatile and highly representative weighting factors which can be used for a range of different applications

   To ensure that the results obtained are representative of the population studied (in this case, the Japanese public), it is necessary to: (1) adopt an appropriate sampling method and (2) obtain more than a certain number of samples.

   For this study, we used the random sampling method to avoid any bias during the sample selection stage. Furthermore, in order to improve the representativeness of the results, we conducted an interview survey with approx. 1,000 samples (individual households) which were randomly selected from across the country, and then analyzed the results in order to compute the weighting factors.

(d) Calculation of statistical values of weighting factors

   Itsubo and Inaba (2005) used a conditional logit model to calculate the representative values of the weighting factors. This study used a random parameter logit model to calculate the representative values and the variability of the weighting factors.

3 Study method

Figure 1 is a flowchart showing how the survey was carried out. This involved four main processes:

1. Sample selection: Sample households were selected for the survey at random, nationwide. This study used a

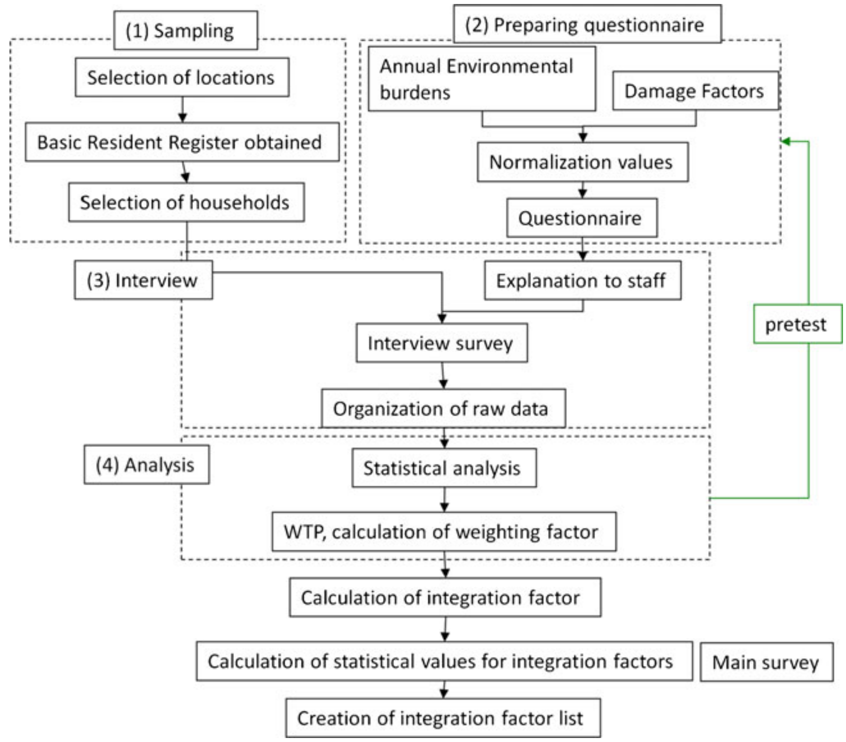


Fig. 1 Survey flow in this study; the flow can be divided into four steps: sampling, making questionnaire, interview, and analysis

two-stage random sampling method in which the locations were selected first, before selecting the samples (households). Specific households were then selected at each location. Selecting the locations first made it easier to use the Basic Resident Register for sampling. The method of sample selection used for the survey can be found in the Electronic supplementary material. We selected approx. 2,000 samples, taking care that the number of samples collected did not fall below 1,000 (we estimated the collection ratio to be approx. 50% before conducting the sampling).

Relationship between the number of sampled points and population in each prefecture is shown in the Electronic supplementary material. We confirmed that there is a good correlation between the number of sampled points and population in each prefecture.

2. Creation of the questionnaire: We created a questionnaire to be used for the interview survey. In this study, the term "questionnaire" refers to a sheet which contained questions and all the information that the respondents needed to know before answering the questions, including a description of various environmental attributes, the profile that bind every attribute used for the conjoint analysis, and questions about the respondents' attributes. The questionnaire used for the conjoint analysis provided quantitative information for each attribute described in the various survey profiles.

   Table 1 shows an example of the profiles used. Respondents were asked to choose from the three policies. Policies 1 and 2 are the profiles adjusted for hypothetical situations including environmental improvements and the additional payment of environmental tax. There

Table 1 An example of one of the profiles provided in the questionnaire

Issue	Policy 1	Policy 2	Policy 3
Per capita loss of life (human health)	1/2 (Life shortened by 1.5 months over 50 years)	None (no shortening of life)	Status quo (life shortened by 3 months over 50 years)
Per capita loss of social assets (social assets)	1/2 (1 million yen lost over 50 years)	Status quo (2 million yen lost over 50 years)	Status quo (2 million yen lost over 50 years)
Plant growth inhibition (plant productivity)	1/4 (1.3% of the forests throughout Japan over 50 years)	1/2 (2.5% of the forests throughout Japan over 50 years)	Status quo (5% of the forests in Japan)
Extinction of species (biodiversity)	1/2 (25 species in 50 years)	No further extinction	Status quo (50 species in 50 years)
Additional tax (per household/year)	10,000 yen added per year (500,000 yen over 50 years)	5,000 yen added per year (250,000 yen over 50 years)	No additional spending

are two manners of monetary attribute, i.e., willingness to pay (WTP) and willingness to accept (WTA). We adopted WTP, because tax payment is seemed to be much closer to daily life rather than receipt of compensation.

The profile used for the current situation is shown in policy 3. This study used the calculation results derived from a set of normalization values to represent the current profile. Table 2 shows these normalization values and the breakdown used (Itsubo et al. 2010). Normalization values in LIME include four kinds of endpoints such as human health (loss of life expectancy), social assets (loss of valuables in human society such as fishery, agriculture, and forestry), biodiversity (extinction of species), and primary productivity (plant growth inhibition). The selection of these endpoints was based on the survey of environmental ethics (Itsubo et al. 2004). Normalization values (NV) can be obtained from the multiplication annual environmental burdens (AEV) for each substance (X) by damage factor (DF) in each impact category (I) in LIME2.

$$NV = \sum_{\mathrm{Impact}} \sum_{X} \left(AEV_X \times DF_{X,\mathrm{Impact}} \right) \tag{1}$$

Several potential damages are excluded from the scope of normalization value, because of the insufficiency of knowledge of environmental science. This may underestimate normalization values.

The profile of the current situation shown here was included in all questionnaires so that the respondents could always compare and contrast the current and hypothetical situations. In addition, in order to help respondents understand the profiles presented, instead of converting the amount of potential damage (annually) into a per capita amount, we illustrated the amount of damage expected if each situation was allowed to continue for 50 years (see the column of policy 3 in Table 1). Furthermore, we added a monetary attribute (environmental tax) in the profile. This is expected to support respondents to imagine the situation that takes place in a daily life.

3. Interview survey: The NOAA Panel (1993) believes it unlikely that reliable estimates of values could be elicited with mail surveys. Face-to-face interviews are usually preferable, although telephone interviews have some advantages in terms of cost and centralized supervision. This study also adopted face-to-face interview. We visited each household surveyed to explain the contents of the questionnaire and collect the answers. In this interview survey, researchers who were familiar with the contents of the questionnaire visited each respondent's house and explained the questionnaire in detail before obtaining the answers.

It was extremely important to ensure that the responses were not based on any misunderstanding by the respondent since, unlike products such as cars and electric appliances, the environmental attributes being evaluated could be difficult for the respondents to conceptualize.

Before conducting the survey, we conducted a pretest to verify whether the contents of the survey had been adequately explained and to confirm that each respondent

Table 2 Normalization values used in this study (calculated by multiplying annual emission of each item by the damage factor and aggregated the results)

Safeguard subject		Human health	Social assets	Primary production	Biodiversity
Impact area (↓), units (→)		DALY	Yen	kg	EINES
Global warming		1.68E+05	7.77E+11	–	–
Destruction of the ozone layer		7.95E+03	5.34E+08	1.71E+09	–
Acidification		–	3.53E+11	1.87E+09	–
Eutrophication		–	4.56E+10	–	–
Photochemical ozone		1.29E+04	5.02E+10	6.66E+09	–
Air pollution in the urban area		2.68E+05	–	–	–
Hazardous chemical substances		3.11E+04	–	–	–
Indoor air contamination		8.38E+04	–	–	–
Eco-toxicity		–	–	–	3.70E−02
Land utilization		–	–	5.12E+10	3.27E−01
Resource consumption	Metals, non-metals and fossil fuels	–	2.95E+12	1.21E+10	7.07E−03
	Biological resources	–		1.08E+11	5.49E−01
Waste		–	7.53E+11	1.70E+09	6.17E−03
Noise		6.89E+4	–	–	–
Standard values (total)		6.40E+5	4.92E+12	1.83E+11	9.27E−1
*LIME1 (used in Itsubo et al. 2003)		4.80E+5	2.61E+12	1.98E+11	7.90E−1

understood what was required. The implementation process for both the pretest and the main survey can be found in the Electronic supplementary material. We used researchers to conduct the interview survey for both the pretest and the main survey.

4. Calculation: The results collected from the respondents were statistically analyzed to derive the weighting factors. These results were then used to calculate the integration factors.

The study used the random parameter logit model (RPL). The conditional logit (CL) model (McFadden 1974) used by Itsubo et al. (2004) is an analytical model widely used in the environmental evaluation field.

The conditional logit model is based on random utility theory. The following discussions are based on studies by McFadden (1974). In the random utility theory, it is assumed that utilities vary at random, and a utility function involving a definite term V and a random term e is given by:

$$\mathrm{Ui} = \mathrm{Vi}(\mathrm{xi}, \mathrm{ti}) + \mathrm{ei} \tag{2}$$

where xi is an attribute vector of a profile i, and ti is a monetary attribute. The probability of a respondent choosing a profile i, namely, a probability Pi for Ui> Uj at a given moment, is:

$$\mathrm{Pi} = \mathrm{Prob}(\mathrm{Vi} + \mathrm{ei} > \mathrm{Vj} + \mathrm{ej}) = \mathrm{Prob}(\mathrm{ei} - \mathrm{ej} > \mathrm{Vj} - \mathrm{Vi}) \tag{3}$$

When the first extreme value distribution is assumed to be a probability distribution of the error term, the probability is expressed by:

$$P_i = \frac{\exp(V_i)}{\sum \exp(V_j)} \tag{4}$$

Parameters are estimated by the maximum likelihood method.

Following on from this, an amount of marginal willingness to pay, a welfare measure, is derived. First, the following utility function is considered where *β is the parameter to be estimated.*

$$\mathrm{V} = \sum \beta_i x_i + \beta_t t \tag{5}$$

The above formula can be also expressed as follows in this study.

$$V = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_t t \tag{5'}$$

Where, the numbers from 1 to 4 are environmental attributes in this study: human health, social assets, plant productivity, and biodiversity, respectively.

A total differentiation of the above gives:

$$\mathrm{dV} = \sum \frac{\partial V}{\partial x_i} dx_i + \frac{\partial V}{\partial t} dt \tag{6}$$

When the utility level does not change (dV=0), and attributes other than the said attribute are invariable, the following is obtained

$$\mathrm{MWTP} = \frac{dt}{dx_t} = -\frac{\beta_i}{\beta_t} \tag{7}$$

But conditional logit model cannot quantify the differences in preference intensity between individuals. The random parameter logit model assumes stochastic variation in the preference intensity. For example, the utility for health damage varies depending on the respondent, which means that each individual, p, has a distinctive factor, β_p, and that these factors are distributed in accordance with certain conditions. The formula used to calculate the probability in the random parameter logit model is shown below. This is expressed by integration using the usual logit probability, $P_{p,i}$, and the density function of a given distribution, f(β):

$$P^*_{j,p} = \int P_{j,p}(\beta) f(\beta|\Theta) d\beta \tag{8}$$

Where,

$P_{j,p}$*: the probability that the individual, p, chooses the option j

Θ: the parameter of the probability density function of β (i.e., means and dispersions)

$$P_{j,p} = \frac{\exp(V_{j,p})}{\sum_k \exp(V_{j,k})} \tag{9}$$

The random parameter logit model assumes a continuous distribution, such as a normal distribution, for f(β).

The selection probability is formulated as SP (simulated probability), as shown below:

$$SP_{j,p} = \frac{1}{R} \sum_r P_{j,p}(\beta^r) \tag{10}$$

R: the number of selections, β^r: the r-th random selection from the density function,

This is used to estimate the log likelihood function (SLL), and the parameter Θ which defines the distribution that maximizes this function (Train 2003).

$$SLL = \sum_p \sum_j d_{j,p} \ln(SP_{j,p}) \tag{11}$$

Where,

$d_{j,p}$is a dummy variable which is set at 1 when the individual, p, chooses the option, j. The distribution function which quantifies the variability in preference

intensity found between different individuals can be derived from these calculations.

4 Results

The results for 952 samples (from 147 locations across the country) are shown in Table 3. The estimated values shown are the results obtained by the maximum likelihood method and represent the relative values compared to the standards (e.g., 1-day loss in the remaining life of one person) given in Table 4. In this case, the results show that utility decreases by 0.215 for each day of life lost. The estimated values are all negative since utility decreases as a result of increased damage. As all attributes were significant at the 5% level, we can see that the Japanese public considers these four safeguard subjects to have environmental value. In addition, the likelihood ratio, which reflects the explanatory power of the random parameter logit model, exceeds 0.2 and therefore displays sufficient consistency for statistical purposes. As a result, we should be able to use the weighting factor obtained here as a value to represent the way in which the Japanese public thinks of the environment.

Table 4 shows the economic values obtained for the unit amount of damage, calculated on the basis of the results.

Here, we derived a weighting factor (WF) for each safeguard subject from the relationship between the estimated values of the social assets and other environmental attributes, assuming that the estimated loss amount for social assets is synonymous with the economic loss. The number of households used was 49,529,000 and the population was 128 million (FY 2005 National Census).

While relatively few studies have been carried out on the economic evaluation of ecosystems, there have been other studies that discuss the best way to calculate WTP for the loss of life. The results of these comparisons are shown in Table 5. The values shown represent the economic value of one year's loss of life.

While ExternE (EC 2005) uses time discounted values, values without time discounting are also provided for reference. If we compare the values with and without time discounting, the representative values all fall within the range from approx. 70,000 to 150,000 € for one year's loss of life. As the ExternE and EPS evaluations focused on Europe, these results could be expected to be similar to those of LIME2, which evaluated the Japanese public. However, it should be noted that different results may be obtained if the same investigation is conducted in another country, especially in a developing country.

Since the weighting factor derived here represents the economic value of 1 U of damage, the economic value of the economic impact resulting from 1 U of environmental load can be derived by multiplying this factor by the relevant damage factor (DF), which represents the size of damage caused by 1 U of environmental load. LIME2 performs a statistical analysis of the integration factor by repeating the calculation shown in formula 12, a number of times using the Monte Carlo simulation and making a list of these results as integration factors (Itsubo et al. 2010).

$$\mathrm{IF}_1^{\mathrm{Impact}}(X) = \sum_{\mathrm{Safe}} \left(\mathrm{DF}^{\mathrm{Impact}}(\mathrm{Safe},X) \times \mathrm{WF1}(\mathrm{Safe})\right) \qquad (12)$$

Where, $\mathrm{DF}^{\mathrm{Impact}}(\mathrm{Safe},X)$: the damage factor of the substance, X, expressed as the unit amount of damage per kilogram. Safe: safeguard subject, Impact: impact category, WF1 (Safe): the economic value of 1 U of the damage sustained by the safeguard subject, Safe (weighting factor), expressed as yen/unit amount of damage $\mathrm{IF}_1^{\mathrm{Impact}}(X)$: the integration factor for substance X (version 1), expressed as yen/kilogram.

We can use the weighting factor, WF1, and the normalization value, NV, to calculate the non-dimensional weighting factor (WF2). The results are shown in Table 4. This result can be derived by multiplying WF1 by the standard value for each safeguard subject and then normalizing the value so that the sum equals 1.

$$WF2(Safe) = \frac{WF1(Safe) \times NV(Safe)}{\sum_{Safe} (WF1(Safe) \times NV(Safe))} \qquad (13)$$

The results show that "biodiversity" and "human health" had relatively high weight and "social assets" had relatively low weight. This indicates that, in a developed country like

Table 3 The results of the analysis of the responses from the main interview survey (952 respondents): negative estimated values represent the decline in utility when damage is suffered or payment is made

Safeguard subject	Estimated value (β)	Standard	t value
Human health	−2.15E−1	1 day/p/h[a]	−4.88
Social assets	−5.35E−2	10,000 JY/p/h[b]	−2.92
Primary production	−5.48E+0	%/h[c]	−6.99
Biodiversity	−5.95E−1	1 EINES/h[d]	−7.03
Tax	−4.00E−5	1 JY/h	−23.0

N: 952, log likelihood: −6481.5, likelihood ratio: 0.22, average annual income: 8.31 million Japanese Yen, *p* person, *h* household, *JY* Japanese yen

t value is 2 or more and is significant at the 5% level

[a] The change in the utility per household for a 1-day loss in the remaining life of one person

[b] The change in the utility per household for JPY10,000 economic loss suffered by one person

[c] The change in the utility per household for 1% of the existing vegetation in Japan

[d] The change in the utility per household for the extinction of one species of vascular plant

Table 4 The results of calculating weighting factors: WF1 is the economic value of the damage suffered per unit of the safeguard subject and WF2 is the relative importance of each safeguard subject (based on the amount equivalent to the annual damage)

Safeguard subject	Standard (unit)	Weighting factors (WF1) economic values (JY/unit)		Amount equivalent to the annual damage	Weighting factors (WF2)	
		LIME2	LIME1 (Itsubo et al. 2003)		LIME2	LIME1(2003)
Human health	1DALY (year)	1.47E+7	9.70E+6	9.39E+12	0.26	0.31
Social assets	10,000 (JY)	1.00E+4	1.00E+4	4.92E+12	0.14	0.21
Primary production	1 ton	4.63E+4	2.02E+4	8.48E+12	0.24	0.23
Biodiversity	1 species	1.42E+13	4.80E+12	1.32E+13	0.37	0.26

The amount equivalent to the annual damage was derived by multiplying the damage factor by the annual environmental load. Total: 3.60E+JPY13 (approx. 7% of GDP)

Japan, while society is provided with a satisfactory level of quantitative resources, the qualitative elements of environmental factors such as health, biodiversity, and forests actually have higher value in terms of public perception.

The total amount of annual damage can be calculated by multiplying the standard value by the weighting factor (obtained above). The result was estimated to be about 36 trillion yen. This is equal to approx. 7% of Japan's GDP. In comparison with the LIME1 survey (conducted in 2003), we can see that the economic value of the safeguard subject has increased. Though it is difficult to make a direct comparison as there are differences in the samples selected, the survey method and the survey period, this demonstrates growing environmental awareness among the Japanese public.

Since we conducted a door-to-door interview survey for LIME2, the respondents were less biased compared to LIME1. Even with random sampling, it is not possible to ignore respondent bias if the collection ratio is low. However, in this study, it was possible to keep the respondent bias to a minimum as we were able to achieve a response rate of about 50%.

A comparison of the estimation results of the random parameter logit model (this study) with the results of the conditional logit model (the model LIME1 applied) is shown in the Electronic supplementary material.

The likelihood ratio of the calculation results from the random parameter logit model increased significantly compared to the results derived from the conditional logit model (increasing from 0.05 to 0.22), demonstrating that the explanatory power of the estimation model had definitely improved. In general, a likelihood ratio of 0.2 or higher for a model indicates high consistency. While the means of the two models were similar, characteristically, the random parameter logit model produced a standard deviation which was not shown by the conditional logit model. Since all these estimation factors were statistically significant, we could verify the validity of the analysis results obtained using the random parameter logit model. Therefore, the random parameter logit model, which can quantitatively express the individual variability in the preferences shown for all attribute variables, should be quite effective in deriving weighting factors along with relevant statistical values.

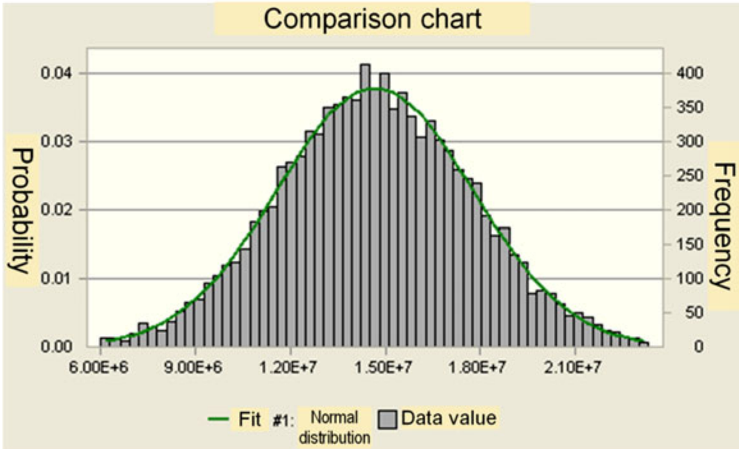
Figure 2 shows the frequency distributions of the weighting factors of human health (WF1), together with the relevant statistical values. The frequency distributions are all distributed symmetrically, showing consistency with the normal distribution. The frequency distributions of the weighting factors of social assets, biodiversity, and primary production can be found in the Electric supplementary material. The variation coefficient of the weighting factor for "social assets" was the largest, implying more variability among individuals compared to other safeguard subjects.

The correlation matrix between the weighting factors of the safeguard subjects can be found in the Electronic

Table 5 Comparison of economic values relating to loss of life

Methodology	Underlying economic evaluation approach	Unit	Representative values		Upper limit	Lower limit
			With discount (3%)	Without discount		
ExternE	CVM	VSL (person)	1.05 M €			
		VOLY (year)	50,000 €	74,627 €	225,000 €	27,240 €
EPS	CVM	YOLL (year)		85,000 €		
LIME	Conjoint analysis	DALY (year)		14.7 MJY (113,000 €)	18 MJY (138,000 €)	10 MJY (77,000 €)

VSL value of statistic life, *VOLY* value of life year, *YOLL* year of life lost, *DALY* disability-adjusted life year



Distribution profile	Normal distribution
Mean	1.47E+7
Median	1.47E+7
Standard deviation	3.08E+6
Variation coefficient	0.21
Kurtosis	3
Skewness	0

Fig. 2 Sampling method in this study: we used two-stage random sampling (first, we selected the locations and then we selected households from the Basic Resident Registry in cooperation with the local governments of the selected locations)

supplementary material. The type of the primary safeguard subject varies depending on the individuals. As shown in this table, all the weights allocated to the safeguard subjects exhibit an inverse correlation, but this is expressed to a varying degree depending on the type of the safeguard subject. For example, an individual who weighs “human health” highly was likely to discount “social assets (−0.13)” and “primary productivity (−0.12)” rather than “biodiversity (−0.05).”

5 Discussion

The key points and issues associated with the weighting methods are listed below:

1. Breaking down the environmental thoughts into patterns

   If individuals have different ways of thinking about the environment, the weights given to the safeguard subject should also vary. Eco-indicator 99 broke down the respondents’ environmental thoughts into three patterns (hierarchist, egalitarian, and individualist) and set weighting factors for each pattern. However, this study did not group the weighting factors according to the environmental thoughts or the attributes of the individuals involved because the test results showed that we could verify that the model had sufficient explanatory power without needing to group the utility function of the population any further. Furthermore, it was felt that if the environmental thoughts were broken down into patterns to create a factor list, a greater burden would be imposed on the practitioners involved in the survey and that this might cause confusion. (However, this does not preclude the possibility that more accurate results might be obtained by breaking environmental thoughts down into patterns.)
2. Effective geographic scope

   Since the population used in this study was the Japanese public, the results can only be used for evaluation purposes within Japan and not for any other country. However, since it is impossible to calculate the WTP for all countries, the WTP for other regions may be estimated based on the results obtained for the region surveyed—a process known as “benefit transfer.” In

Table 6 Main differences in the study procedures between LIME1 and LIME2

	LIME1	LIME2	Purpose of improvement by LIME2
Method of survey	Interview survey (at the venue)	Interview survey (by visit)	Development of weighting factors with high representativeness and general versatility
Sampling method	Mall intercept	Random sampling	
Number of sample responses	400	952	
Survey location	Tokyo	Nationwide	
What is obtained from the calculation	Representative value	Representative value and statistical value	Calculation of the statistical values of the weighting factors
Model	Conditional logit model	Random parameter logit model	

most cases, per capita GDP is extrapolated in terms of benefit transfer. According to the calculation results obtained from our study, we were able to confirm that a similar result could be obtained for a developing country with similar economic conditions. However, the WTP may not only be affected by economic conditions but also by other factors such as culture, education, and religion. Further investigation should be carried out to derive a versatile WTP which can be applied globally.

3. Effective temporal scope

As illustrated by the fact that the IPCC publishes a report every 4 or 5 years, the interests of society change along with scientific progress and new insights. It is natural to expect that the environmental thoughts of members of the public will also change, accordingly. While the results of this study were generally similar to those of LIME1 (Itsubo et al. 2004), overall, we observed changes such as an increase in the public's willingness to pay and a stronger preference for "biodiversity." It would, therefore, be useful to conduct further surveys to recalculate weighting factors on a regular basis.

6 Conclusions

Integration (the final process of LIME assessment) converges the indicators by allocating the weight of the safeguard subject to the amount of damage suffered, using the results obtained from the damage assessment. Accordingly, for the purposes of this study, we had to obtain convincing weighting factors for the safeguard subjects which could then be used to represent the environmental thoughts of the Japanese public.

We focused on the use of conjoint analysis since the methodology of conjoint analysis was considered to be consistent with our aim of obtaining highly representative weighting factors that could be allocated among the safeguard subjects.

Our study developed policy profiles which used the four types of safeguard subject defined by LIME as environmental attributes (human health, social assets, biodiversity, and primary production). The damage factors and the normalization values determined from the annual environmental load were used for the current situation, which then served as the baseline for comparison with the hypothetical policies presented.

The process of integrating LIME1 (Itsubo et al. 2004) and LIME2 (this study) and the differences between these two studies are summarized in Table 6.

In order to obtain highly accurate estimates of the weighting factors, we needed more than a certain number of respondents. For this study, we were able to obtain approx. 1,000 survey results from random sampling and then perform a series of statistical analyses on the data collected. (Few, if any, large-scale surveys like this one have been conducted to derive LCIA weighting factors in this manner, even in the field of environmental economic evaluation.)

The random parameter logit model was applied to the response results obtained in order to derive the economic value (per unit) of the safeguard subject by means of analysis carried out using the maximum likelihood method. We were able to confirm that the results obtained, for all safeguard subjects, were statistically significant and that the model used had high explanatory power. Accordingly, it was demonstrated that the respondents had fully understood the explanation provided in the questionnaire before answering the questions, and then answered the questions based on their own environmental thoughts (without bias). The statistical values were calculated in this study, in addition to the estimated values, by which we successfully visualized the individual variability in the environmental values expressed.

The results showed that "biodiversity" was the highest priority, followed by "human health" and "primary production," while a lower weight was assigned to "social assets." This is slightly different from the results of LIME1, where the highest priority was placed on "human health." The economic values obtained for all the safeguard subjects were higher than those obtained by LIME1. Though the results cannot be compared unconditionally since there are a number of differences between the two surveys in terms of the survey period, the respondent group, and the data shown in the questionnaires, they can be assumed to reflect the recent growth in environmental awareness and the fact that the survey was conducted in the suburbs.

As a result of these achievements, it has now been possible to calculate integration factors for LIME2. The results have already been published in Japan as a factor list, which is already in use by a number of Japanese companies. Though some issues still remain to be resolved, such as the effective geographical or temporal scope, for example, we believe that this study has considerable social significance because it illustrates and quantifies findings which could have a significant impact on society.

References

Ahlroth S, Nilsson M, Finnveden G, Hjelm O, Hochschorner E (2011) Weighting and valuation in selected environmental systems analysis tools—suggestions for further developments. J Clean Prod 19:145–156

European Commission (1998) ExternE externalities of energy vol.7 methodology 1998 update

European Commission (2005) ExternE, externalities of energy, methodology 2005 update, edited by Peter Bickel and Rainer Friedrich

European Commission (2008) The economics of economics and biodiversity, an interim report
Finnveden G, Eldh P, Johansson J (2006) Weighting in LCA based on Ecotaxes development of a mid-point method and experiences from case studies. Int J Life Cycle Assess 11:81–88
Goedkoop (1995) The eco-indicator 95. NOH report 9523. Pré consultants, Amersfoort
Goedkoop M, Spriensma R (1999) The Eco-indicator 99, a damage oriented method for Life Cycle Impact Assessment, Methodology Report
Green PE, Krieger AM, Agarwal MK (1991) Adaptive conjoint analysis, some caveats and suggestions. J Marketing Res 28:215–222
Hauschild M, Wenzel H (1997) Environmental assessment of products. Volume 2: scientific background. Chapman & Hall, London
ISO 14040 (2006) International standard, Environmental management—life cycle assessment—principles and framework
ISO 14044 (2006) International standard, environmental management—life cycle assessment—requirements and guidelines
Itsubo N (2000) Screening life cycle impact assessment with weighting methodology based on simplified damage functions. Int J Life Cycle Assess 5(5):273–280
Itsubo N, Sakagami M, Kuriyama K, Washida T, Kokubu K, Inaba A (2003) Development of weighting factor for LCIA based on conjoint analysis. J Environ Sci 15(5):357–368 (in Japanese)
Itsubo N, Sakagami M, Washida T, Kokubu K, Inaba A (2004) Weighting across safeguard subjects for LCIA through the application of conjoint analysis. Int J Life Cycle Assess 9:196–205
Itsubo N, Inaba A (2005) Life Cycle Impact Assessment Method, LIME—a methodology and database for LCA, environmental accounting and ecoefficiency. Japan Environmental Management Association for Industry (in Japanese)
Itsubo N, Inaba A, Ii R, Ikaga T, Kubo T, Sakagami M, Nagata Y, Hama Y, Hayashi K, Hirosaki J, Motoshita M (2010) LIME2—an environmental impact assessment method supporting decision making (in Japanese)
McFadden D (1974) Conditional logit analysis of qualitative choice behavior. In: Zarembka P (ed) Frontiers in Econometrics. Academic Press, pp 105–142
Mettier TM, Hofstetter P (2005) Survey insights into weighting environmental damages. Influence of context and group. J Ind Ecol 8 (4):189–209
Müller-Wenk (1994) The Ecoscarcity method as a valuation instrument within the SETAC-Framework, in Integrating Impact Assessment into LCA, SETAC-Europe, Bruxelles, pp 115–120
NOAA Panel (1993) Arrow K, Solow R, Portney PR, Leamer EE, Radner R, Schuman H. Report of the NOAA Panel on Contingent Valuation, January 11
Soares SR, Toffoletto L, Dechênes L (2006) Development of weighting factors in the context of LCIA. J Clean Prod 14:649–660
Steen B (1999) A systematic approach to environmental priority strategies in product development (EPS) version 2000—models and data of the default method
Stern (2006) Stern review, the economics of climate change, HM Treasury, 2006 October
Train K (2003) Discrete choice model with simulation, 2003
Yasui I (1998) A new scheme of life cycle impact assessment method based on the consumption of time. 3rd Int. Conf. on Ecobalance, Tsukuba, p 89
Weidema BP (2009) Using the budget constraint to monetarise impact assessment results. Ecol Econ 68:1591–1598